TECHNICAL REFERENCE DOCUMENT

UNDERSTANDING THE EFFECT OF ENVIRONMENTAL FACTORS ON HUMAN HEALTH AND WELL-BEING

1. Introduction

What if we could reduce the incidence, or eliminate the most virulent cases, of deadly diseases like malaria, cholera, and West Nile encephalitis? Malaria and cholera killed more than 2.7 million people last year, primarily in the developing world; West Nile virus has now been detected in all but one of the lower 48 states.

Since mosquitoes are the principal vectors for both malaria and West Nile virus, environmental factors often set the stage for optimal conditions for their spread and are important in determining their transmission, intensity and duration. By using *in situ* and remotely sensed data to monitor weather patterns, such as temperature and rainfall, and their effects on soil moisture and humidity, warnings may someday be available for high-risk areas up to a month in advance. Health officials could use these "red flag" warnings to plan their prevention efforts, perhaps averting a potentially deadly outbreak.

The effective combination of *in situ* and remotely sensed data, indicators, and models could also be used in computer simulations to estimate the risk of cholera. Ocean temperature and circulation affect the proliferation and movement of phytoplankton blooms that harbor cholera bacteria. Satellite data can identify large-scale spatial and temporal bloom development while *in situ* buoys and stream gauges can provide local verification.

What if? This quest has proven valuable in the past. People born at the beginning of the 21st century, on average, can expect to live significantly longer and healthier lives than those born just over a century ago. Much of that increase was gained by environmental changes including improved sanitation, purified water, more effective control of disease vectors and reservoirs, cleaner air, and safer use of chemicals in homes, gardens, factories, and offices.

Continued improvements in quality of life and longevity will require a better understanding of the causes, development and progression of common diseases and disorders—and how they relate to environmental factors. For example, what are the environmental factors behind the burgeoning increases in vector-borne diseases (e.g., malaria, West Nile virus) and chronic diseases with possible links to environmental exposures (e.g., breast cancer, Parkinson's disease and asthma)? What are humans being exposed to? How can we improve prediction of outbreaks of acute diseases such as malaria and cholera?

Most health problems in an individual arise from the interplay of a complex array of factors including genetic susceptibilities, stress, nutrition, age, stage of development, and environmental exposures. With the sequencing of the human genome, rapid progress in understanding human genetic susceptibilities is expected. One of the most difficult of these factors to monitor and assess are environmental exposures.

There are a variety of concerns or societal imperatives, which take a different form from the obvious or traditional concerns. These societal imperatives include a growing world population, projected to roughly double in the next few decades that will increasingly demand access to crucial resources like clean water and plentiful food. The concentration of populations is shifting from rural areas to urban centers, many in low-lying coastal regions or seismically active zones. In the U.S., more than half of the population lives within 50 miles of our coasts, and these areas are particularly vulnerable to storm surges and flooding. We rely upon coastal regions for healthy fisheries, and reliable transport and navigation. Increased dependence on infrastructure networks (roads, power grids, oil and gas pipelines) increases our potential vulnerability to natural disasters, and requires improved understanding of the complex workings of Earth systems in order to protect society and manage our resources in a more efficient and effective way.

A well-designed, coordinated integrated United States Earth Observation System (IEOS) would contribute significantly to providing data and products on many environmental factors that influence stress (extreme weather events, noise), nutrition (price and availability of food), and most importantly exposures (air and water pollution, pathogens) that directly affect human health and well-being. The potential benefits would be enormous (see Table 1).

• Improved visibility and reduced haze for tourism • Improved understanding of global transport of pollutants for policy making • Warnings for sensitive populations to change activity patterns • Early warnings for harmful exposures • Early warnings for increases in disease vectors • Improved mitigation/ prevention programs. • Reduced releases of air and water pollutants • Reduced use of pesticides and chemicals	• Reduced lung-related and water-born diseases & premature death • Reduced hospital admissions & use of medicines • Reduced absences from work and school; lower sick pay costs • Improved resiliency of crops; increased yields • Prevention of environmentally related diseases • Reduced exposure to toxic substances in air and water

Table 1. Potential Benefits of Increased Data on Environmental Factors Affecting Human Health and Well-Being

2. User Requirements

Over the past fifty years, the public has expressed a significant interest in understanding the relationships between health and environmental parameters. This has fostered an increasing demand that the best science be available to inform their own decisions and those of service providers and policy-makers. In addition, high priority requirements have been articulated by national and international groups including the National Academy of Sciences, Institute of Medicine, Intergovernmental Panel on Climate Change, U.S. National Assessment, Arctic Monitoring and Assessment Program, UN Environmental Program, World Health Organization, the World Meteorological Organization, and others.

The optimal approach is to combine ground or *in situ* and remote observation data, information, indicators, models, research, and other decision support systems to focus on an issue. These materials can be distributed widely using communications information systems and web portals, and effectively provide the information and tools for the public and decision-makers to make decisions about their daily lives that can influence health and well-being.

Data and data products relevant to human health and well-being include, but are not limited to the following areas:

- Air quality and pollution transport
- Water quantity and quality, especially for human use
- Hot spots of pollution in wetland and coastal areas
- Fate of pathogens in marine and other low oxygen environments, such as, aquifers, mountain tops and caves
- Fate and transport of chemicals in the terrestrial, aquatic, and marine environments
- Impact of environmental changes and agriculture on biodiversity
- Special regions valued for recreational, religious, or aesthetic purposes
- Search for natural substances with medicinal/commercial value
- Environmental conditions that influence disease transmission from animals to humans
- Environmental conditions that affect the spread and control of emerging or re-emerging diseases
- Disease vector and reservoir habitats and variations in range
- Safe and adequate supply of food
- Urban environment and growth
- Noise/odor levels
- Radioactivity
- Transportation patterns and travel statistics
- Sensitive resource and environmental data for transportation planning
- Land use, urban form, population data, including GIS, for transportation planning
- Human activities and location for exposure assessment and resource management
- Weather and climate
- Invasive species, particularly those affecting humans

3. Existing Capabilities and Commonalities

Vision

An information system of environmental and health factors that are important to human health and well-being would integrate satellite measurements with ground-based measurements, human activity data, and models to describe and track pollution sources, concentrations, and human activities that influence exposure and impact human health. Other components of the global Earth observation system of systems will develop data to reduce disasters, protect and wisely use natural resources, understand and predict climate variation, support sustainable agriculture, forecast weather, and sustain areas valued for recreational, religious or aesthetic purposes. Since these components will also provide data for improving human health and well-being, there will be many observational systems to build upon. Such a system will augment existing and planned activities by collecting additional data and using data analysis tools (models, bioinformatics and state-of-the-art information technology) to integrate the data into meaningful sets of public health indicators both for short-term predictions, future forecasts, or retrospective evaluation.

Such a system will draw upon indicators of health and disease as well as some environmental public health indicators that exist today, but there are gaps and thus challenges ahead to develop a more comprehensive set of indicators. Observations will be selected to address these gaps including the tracking of pollutant sources, pollutant and pathogen concentrations and transport, and human locations and activities. Data analysis tools will be used to integrate the data and provide indicators of possible adverse health impacts on specified populations. Pilot projects will use an integrated suite of existing and new indicators to identify short and long-term changes in stressors-of-concern and changes in the human, land cover, environmental and social factors that effect human health and well-being. The value of IEOS will be judged on how well it succeeds in improving human health and well-being, and the proposed system is a critical component of the system of systems.

The following are general recommendations for establishing and operating a health information system:

- Establish a forum for identifying appropriate sets of indicators that can be used to evaluate and improve human health and well-being.
- Determine the data, data analysis tools, and data dissemination requirements for these indicators to be used as part of health IS.
- Integrate with other components of the global Earth observations system of systems. (i.e., the urban land cover project that characterizes the built environment) to generate the needed information
- Determine the cost, feasibility, and technical requirements for establishing each of the proposed indicators,
- Identify critical methods and development needs for partial or full implementation of a health information system (i.e., real time sensors that provide higher spatial and temporal resolutions, flexible indicators, models and information systems, bioinformatic tools, GIS)

- Establish mechanisms for transferring these or other new technologies into a health information system as they become available.
- Develop the partnerships and infrastructure for developing, operating, and enhancing a health information system.
- Pilot test a suite of the most feasible indicators.
- Initiate methods/develop activities in sensor/measurement technology, data analysis tools, and information archival/dissemination.
- Develop systems that provide both real-time availability along with archived data for trends and long-term effects.
- Develop a core users group that will have access to and demonstrate the utility of the information.
- Build an across the board system for training and education at the intersection of environment and health observations, data collection and analysis.
- Develop and monitor well defined measures that will demonstrate success.
- Provide data and data products at a reasonable cost

Background

All the components of this integrated Earth observation system contribute to improving human health and well-being. Researchers, service providers, policy makers, and the public use Earth observations to make decisions and take actions. These decisions and actions help reduce the impact of disasters, protect and manage natural resources, adapt to and mitigate climate variation, support sustainable agriculture, forecast weather, protect areas valued for recreational, religious, or aesthetic purposes, and prevent disease/dysfunction due to environmental exposures or conditions that increase the likelihood of transmission of water- or vector-borne diseases.

The ability to predict the appearance and intensity of diseases has long been a goal of public health workers, economic planners and ordinary citizens. For those diseases that are influenced by environmental factors, the development of predictive models will open the door to the possibility that if one could link risk of disease with certain variables, one could eventually apply these models to predict occurrence and possibly control or prevent these diseases in human populations. Enhanced Earth observations that lead to better air quality data and the ability to predict air pollution episodes would contribute to improvements in human health via: reduced incidence, acute attacks and deaths from chronic respiratory diseases such as asthma; fewer air pollution-related emergency room visits; and fewer days absent from school or work. Air pollution affects the environment in many ways that ultimately impact on our health and well-being: by reducing visibility, damaging crops, forests, and buildings; acidifying lakes and streams; stimulating the growth of algae in estuaries; and the build-up, or bioaccumulation of toxics (e.g., mercury) in fish and animals. Rapid development and urbanization around the globe has created air pollution that threatens people everywhere, as air pollution can travel great distances across oceans and national boundaries.

Characteristics of Existing Earth Observation Capabilities

The IEOS anticipates a thoughtful mix of system elements to address the goals of societal benefits. This is true of the area of human health and well-being. To make progress on complex questions requires a variety of data from populations, the Earth, atmosphere, weather and other areas, combined with monitoring, modeling, and decision support research and systems. As such this issue become "cross cutting" with all the other issues contemplated by IEOS.

The IEOS contemplates using a variety of measures and monitoring along with models, indicators, and decision support systems to address the requirements of users. A fairly extensive suite of measures have been developed and applied over the years, some specific to these issues and others adapted from other applications to focus on human health and well-being.

The use of these systems for human health studies has focused primarily on studies of land surface variables and their application to epidemiological studies. Earth remote sensing systems has been used since the launch of Landsat in 1972, and a combination of remote sensing and surface measures has provided useful data and information for other important health issues such as extreme weather, air pollution, UV radiation, ocean/coastal issues, and contaminant transport.

Socioeconomic data, including data on both human activities and health, are essential to understanding fully the impact of environmental factors on human health and well-being. It is the linkage or combination of those data with environmental measurements that allows for research in these areas to proceed and for preventive and remedial strategies to be developed and implemented. Although the scope of this program is limited to data and data products that come from observing the Earth, the agencies responsible for its implementation should collaborate with the organizations that collect and process socioeconomic data to provide user-friendly links to relevant data and data products. Of special note is the major Centers for Disease Control and Prevention (CDC) effort to improve environmental public health tracking which will provide critical health data to tie into the various environmental monitoring systems.

A description of the application of existing remote sensing systems to many of these major health issues follows.

Epidemiology

The use of a combination of data sources including remote sensing for studies is based upon the fact that the temporal and spatial distribution of water- and vector-borne diseases (as well as their vectors) are dependent upon complex factors. These factors include a combination of human, demographic, socioeconomic, habitation, and environmental factors such as temperature, soil type and moisture, humidity, landscape structure, rainfall, vegetation, and water bodies, most of which can be measured, observed, and/or modeled with data from a combination of existing and planned systems. These environmental variables influence the suitability of any site as a habitat for both vectors and pathogens as well as their viability, abundance, breeding success, and transmission. Remote sensing and *in situ* observations contribute valuable data on these environmental variables from which epidemiological and demographic information can be developed. The resulting observations and information can be applied to: a) categorizing, mapping, and modeling parasite, pathogen, vector, and host habitats, b) observing changes in habitats, c) predicting related changes in host or vector populations, and d) creating risk maps useful for control programs.

The primary remote sensing systems, which have been used for the land characterization aspects of epidemiological studies for infectious and vector-borne diseases, are passive remote sensing systems such as the MSS (Multispectral Scanner), TM, NOAA's Advanced Very High Resolution Radiometer (AVHRR), and the Systeme Pour l'Observation de la Terre (SPOT) of France. High spatial resolution sensors (generally, resolution less than 1km by 1km) include the Landsat series of satellites, beginning in 1972, the SPOT series, initiated in 1986, and, more recently, IKONOS and MODIS (NASA's Moderate Resolution Imaging Spectroradiometer). While these sensors offer higher resolution imagery and have been used for a number of epidemiological studies, factors such as cloud cover, data availability, low temporal frequency, and/or high cost have limited the use of these systems.

Low spatial resolution sensors include: the NOAA series, operating since 1978, which carry the AVHRR; the Meteosat series from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), first launched in 1977, carrying the High Resolution Radiometer (HRR) and designed for meteorological applications. These sensors suffer from cloud cover, but often higher data availability or coverage that helps address temporal issues.

USGS land cover data characteristics and a variety of geospatial data sets (terrain, hydrology, soils, geology, transportation) plus census data are important data sources for epidemiology studies. The USGS National Biological Information Infrastructure (NBII) is an electronic information network made up of many partners that provides access to biological data and information on our nation's plants, animals, and ecosystems. Data and information maintained by federal, state, and local agencies, universities, nongovernmental organizations and the private sector are linked through the NBII gateway and made accessible to a variety of audiences, including decision makers, researchers, natural resource managers, educators, and the general public.

The NBII Wildlife Disease Information Node is developing an integrated monitoring and information system to document the prevalence and spread of wildlife and zoonotic diseases both spatially and temporally via a nationwide web-based interactive mapping application and a web-based animal mortality reporting system that could be used to analyze disease trends, distribution, relationships, and patterns. In addition, disease reporting systems such as CDC's ArboNet are important systems for integration into an Earth observation system.

Characterizing land use patterns and land cover is vital to understanding relationships between human populations, environmental stressors and disease. Remote sensing of changes in land use/land cover patterns (urbanization, defoliation, etc.) are currently available from the Landsat series of observations including IKONOS and MODIS as well as the aircraft system AVIRIS. This information is useful for characterizing population growth patterns (e.g., urban/suburban sprawl) between official U.S. census reports.

Satellites have yielded data products including normalized difference vegetation index, middle infrared reflectance, land surface temperature, air temperature and altimetry useful to health researchers. Studies supported by the National Institute of Allergy and Infectious Diseases

(NIAID) have been conducted on a variety of diseases using satellite technology including cholera, malaria, echinococcosis, sleeping sickness, Lyme disease, schistosomiasis, West Nile virus, and Venezuelan equine encephalitis. Researchers have also studied Rift Valley Fever, Ebola, onchocerciasis, trypanosomiasis, dengue fever, and bluetongue disease using data derived from various satellite technologies. Much of this work would be improved by increased spatial, temporal, and spectral resolution, as well as improved correlations with epidemiology, demographics, and on-the-ground or *in situ* "truthing."

The following is a list of resources used by health researchers on an *ad hoc* basis. Although these systems represent major resources and significant amounts of work, they remain far removed from the potentially productive data demands of health researchers. Information on these websites reflects the necessity of remote sensing (RS) expertise to describe the capabilities of current instruments to scientists and to create user-friendly, standardized data products in collaboration with the consuming researcher. Individual research teams have developed several other data products for use in specific projects. These are not "in place" and fall under the category of data/data product sharing.

Elevation data: The Land Processes Distributed Active Archive Center (DAAC) website at the United States Geological Survey (USGS) provides 1km x 1km spatial resolution (GTOPO30—global topographical data) elevation data. Other higher resolution elevation data are available from USGS through its web site at http://edc.usgs.gov/products/elevation.html. In addition, the Shuttle Radar Topography Mission (SRTM) provides useful Interferometric Synthetic Aperture Radar (IFSAR) data from over 80 percent of the landmass of the Earth between 60 degrees North and 56 degrees South latitudes in February 2000. Digital Chart of World and the DEMs available in that product supplies uniform coverage for the World.

Weather: A large series of National Oceanic and Atmospheric Administration (NOAA) weather data systems are collected and archived. These examples are discussed elsewhere, but some important examples include:

- Real-time rainfall estimation, where accumulations (1-, 3-, 6-, and 24- hours) in the Americas is available every half hour through NOAA from Geostationary Operational Environmental Satellite (GOES) data, and resolution is 4 km (http://orbit35i. nesdis.noaa.gov/arad/ht/ff/index.html).

- Tropical Rainfall Measuring Mission (TRMM), which reports daily and monthly rainfall products for selected areas are available through the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC). The system is called TRMM Online Visualization and Analysis System (TOVAS) (http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/hydrology/. TRMM_analysis.html).

- The Global Precipitation estimation, supplying monthly mean precipitation data from the Global Precipitation Climatology Project (GPCP) on 2.5 x 2.5 degree (latitude x longitude) grids from 1986-2000 http://cics.umd.edu/~yin/GPCP/.

- Monthly data on precipitation estimates from several sources is provided on a 1 x 1 degree grid from Jan 1979-Jan 2001; source is NASA/DAAC (http://yang.gmu.edu/~yang/nasacd/www/gpcp_global_precip.html).

Wind Speed, Direction, and Height: Upper atmosphere winds are observed by GOES maintained by the National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service (NOAA/NESDIS). Central and North America are covered. These data can yield water vapor winds, infrared cloud drift winds, and visible cloud-drift winds. (http://www.orbit.nesdis.noaa.gov/smcd/opdb/goes/ winds/wind.html)

Sea Surface Winds: Global, near real time data derived from NASA's Quick Scatterometer (QuickSCAT), European Remote-Sensing Satellite-2 (ERS-2) and Defense Meteorological Satellite Program/Special Sensor Microwave Imager (DMSP/SSMI) are available as a 22-hour composite. (http://wwwo2c.nesdis.noaa. gov/owinds/winds_browse.htm)

Sea Surface Temperature (SST): Near-real time (hourly) data on SST are composed and posted on the NOAA CoastWatch Ocean Product Server every 3 hours from NOAA/NESDIS; historical data is archived and available through the Satellite Active Archive (SAA). (http://wwwo2c.nesdis.noaa.gov/cwatch/ gsst_browse_framed.htm)

Sea Height Anomaly: Sea height and significant wave height from the Ocean Topography Experiment (TOPEX/Poseidon) are available through NOAA/NESDIS – NASA with a 2-day delay; height resolution under the satellite is 4-5 cm (http://www.aoml.noaa.gov/phod/dataphod/ work/trinanes/INTERFACE/index.html)

Ocean Color: Sea-Viewing Wide Field of View Sensor (SeaWiFS) provides daily near real time chlorophyll concentrations through NASA/GSFC/DAAC (http://seawifs.gsfc.nasa.gov/cgibrs/ seawifs_subreg_12.pl) and ocean true color at 4 km resolution (http://seawifs.gsfc. nasa.gov/cgibrs/seawifs_subreg.pl?N=3).

Land Surface Reflection and Emission: University of Maryland Moderate Resolution Imaging Spectroradiometer (MODIS) Land Products are available through the Land Rapid Response System of the University of Maryland and NASA. Resolution varies from 250 m to 1 km. (http://rapidfire.sci.gsfc.nasa.gov/)

Aerosol and Ozone: The Total Ozone Mapping Spectrometer (TOMS) follows dust storms, forest fires, and biomass burning. The latest 3-day composite index is available through http://toms.gsfc.nasa.gov/aerosols/today_aero.html; the daily total global ozone column is also available at http://toms.gsfc.nasa.gov/teacher/ ozone_overhead.html

Vegetation Index: The Satellite Probatoire d'Observation de la Terre 4 (SPOT-4) polar orbiting satellite provides an indication of vegetation in the Normalized Difference Vegetation Index at 4 km resolution; 10-day and monthly periods from 1998-2002 are available, and 1982-present data are available from NOAA/AVHRR through the Advanced Relay and Technology Mission (ARTEMIS) and agrometeorology (AGROMET) Data and Information of the Food and

Agriculture Organization (FAO) of the United Nations (http://metart.fao.org/~~/gbr/E-VVGTGL.htm)

Water vapor: Infrared, visible, and water vapor images are available from GOES-8/10, GMS-5 and Meteostat-7, and the NASA Global Hydrology and Climate Center server at http://wwwghcc.msfc.nasa.gov/GOES/. Water vapor data are also available at http://www.archive.arm.gov/.

Human Activity and Location Patterns

Patterns of human activities and locations are necessary to estimate accurately and forecast human exposures. For instance, in a framework called Landscan the capability currently exists to integrate census data on people's home and work locations with GIS data to quantify more accurately commuting activities. This allows for improved understanding of traffic patterns and the time an individual or population spends in transit potentially exposed to motor vehicle emissions. Similar technologies are being used by EPA, and they could be extended to characterize better other activities and locations.

Extreme Weather and Climate-Related Events

There is a lot of discussion as to what issues on human health and disasters/hazards should be addressed here versus the disasters/hazards societal benefit. The corresponding technical reference document, *Reduce Loss of Life and Property from Disasters,* can provide the reader a richer evaluation of these issues.

Events can have direct and/or indirect effects on all types of human settlements and activities. Weather, climate, and extreme weather-related events like drought and storms, hurricanes, tornados, and cyclones with excessive rainfall, often resulting in serious flooding can create health risks directly through injury, infection, and mortality as well as indirectly from epidemics of water-borne diseases such as cholera and typhoid fever and vector-borne diseases such as malaria and dengue fever. In addition, extreme weather can also impact the health and well-being of populations through forced movement of populations, loss of shelter, contamination of drinking water, destruction of infrastructure, loss of healthcare facilities, and loss of food production and associated malnutrition

A wealth of remote sensing resources for weather and climate information is available to urban and rural planners and other decision-makers for addressing environment-related health problems. The visible and infrared sensors aboard NOAA's GOES (Geostationary and Polar-Orbiting Weather Satellites) and POES (Polar Orbiting Satellites) series make available views of weather phenomena on both coasts and oceans of the U.S. and South America, along with Europe's Meteosat, Japan's Geostationary Meteorological Satellite (GMS), and India's Insat.

NASA's Tropical Rainfall Measuring Mission (TRMM), a joint mission between NASA and the National Space Development Agency of Japan (NASDA), monitors and studies tropical rainfall and the associated energy release which helps drive global atmospheric circulation, which, in turn, shapes weather and climate around the world. Seawinds, carried on Quickscat, measures winds over the oceans, which are critical in hurricane assessment. The TOPEX/Poseidon (Topography Experiment) and follow-on, JASON missions, provide sea surface height, a key to ocean circulation and global climate.

MODIS and MOPITT (Measurements of Pollution in the Troposphere) on NASA's Terra spacecraft, monitor a variety of weather and climate parameters such as temperature, clouds, moisture, atmospheric pollutants, and aerosols. The Earth's radiation budget, critical to climate studies, is provided by CERES (Clouds and the Earth's Radiant Energy System) on TRMM and Terra; ACRIMSAT (Active Cavity Radiometer Irradiance Monitor) measures the total of solar energy, which reaches Earth, important to climate and global warming studies. Climate data on cloud and radiative processes for three climate regions (the U.S. Southern Great Plains, the Tropical Western Pacific, and the North Slope of Alaska) are available at http://www.archive.arm.gov/. These regional data are used to improve both cloud system models and general circulation models.

Some of the other important remote sensing systems that provide weather and climate observations and data useful to health studies are the MISR (Multi-Angle Imaging Spectroradiometer) on Terra (observes temporal changes in dust, clouds, and surface); the U.S. Defense Meteorological Satellite Program (DMSP) and its suite of measurements of such phenomena as clouds, lightning, and rainfall; the Earth Radiation Budget (ERBS) for climate-related processes; UARS (Upper Atmosphere Research Satellite) for energy input, chemistry, and dynamics of the upper atmosphere, and coupling between the upper and lower atmosphere; and TOMS (the Total Ozone Mapping Spectrometer) which provides daily mapping of the Earth's atmospheric ozone globally.

Air quality/air pollution

Air pollution affects the environment in many ways that ultimately impact on our health and well-being: by reducing visibility, damaging crops, forests, and buildings; acidifying lakes and streams; stimulating the growth of algae in estuaries; and the build-up, or bioaccumulation of toxics (e.g., mercury) in fish and animals. Rapid development and urbanization around the globe have created air pollution that threatens people everywhere, as air pollution can travel great distances across oceans and national boundaries.

Exposure to air pollution from both natural and anthropogenic causes is considered to be one of the most serious world-wide health problems, and is expected to become worse with changes in the global climate and increased industrialization throughout the world. Exposure to air pollution may cause or exacerbate asthma, other pulmonary diseases, and cardiovascular disease. Epidemiologic studies conducted over the last ten years document increased rates of allergic respiratory disease. Urban particulate air pollution is associated with the rising rates of asthma and rhinitis. Individual susceptibility to air pollution is associated with genetic and dietary factors and occurs as a genetic predisposition to development of asthma and allergy or as a co-factor, exacerbating disease severity. A recent study reports an increase in heritable gene mutations in the offspring of male mice exposed to urban air pollution and supports the conjecture that air pollution poses a genetic risk to humans and wildlife. Particulate concentration is increased by motor vehicles, urbanization, and industrial processes, and by natural and man-made disasters.

Why now? Over 141 million people live in U.S. counties that exceed National Ambient Air Quality Standards. The potential of Air Quality (AQ) data, modeling, indicators, and forecasting for societal benefit is great in developing regions and in countries with substantial and increasing industrialization and urbanization. An IEOS program targeted to air quality could provide contributions to integrated data streams; enhanced capabilities from measurement platforms, as well as access to data to foster forecast modeling; promote good will through capacity building; improve urban, local and regional understandings of air quality degradation; and develop decision support systems to respond to urban needs and decision-making.

A potential outcome would be an enhanced observational system integrated with modeling, indicators, and decision support tools which would improve the ability to forecast air quality across large parts of the country (and in other parts of the world) for which forecasts are not currently available, and could provide better information about emissions and transport mechanisms on regional to international scales. It is vital to provide important information to help the public avoid harmful exposures and to help air quality managers cope more effectively with air pollution episodes over the short and long terms.

Understanding air quality and its influence on people and the environment requires enhanced surface-based observations. Existing surface monitoring networks should be integrated with air quality observations from other platforms, including satellites, ships and aircraft, and used to develop and evaluate improved predictive indicators, models and decision support tools.

In situ and remote measurements of atmospheric trends for particulate transport as a function of altitude, wind direction, and velocity will facilitate rapid identification of geographically at-risk populations. These data, coupled with *in situ* measurements and indicators of particle concentration and size, and measurements of individual susceptibility to air pollution, would permit analysis of exposure and onset or exacerbation of allergic disease over time.

For decades weather forecasters have used satellites to help forecast weather. Researchers are now showing that satellites can also help with forecasting air quality. In summer 2003, NASA and the EPA will prototype the use of satellite data in EPA's AIRNow Air Quality Index (AQI), an index for reporting daily air quality, as a forecast tool. Through AIRNow, the AQI tells how clear or polluted the air is and the potential health effects. EPA includes five major air pollutants in the AQI: ground-level ozone, particulate matter (PM), carbon monoxide, sulfur dioxide, and nitrogen dioxide. (See Figure 1) EPA uses a network of monitors to record pollutant ground concentrations that are used to calculate the AQI level. State and local agencies report the local AQI to the public daily. Forecasts can help local officials & the media anticipate pollution levels and announce public health warnings.

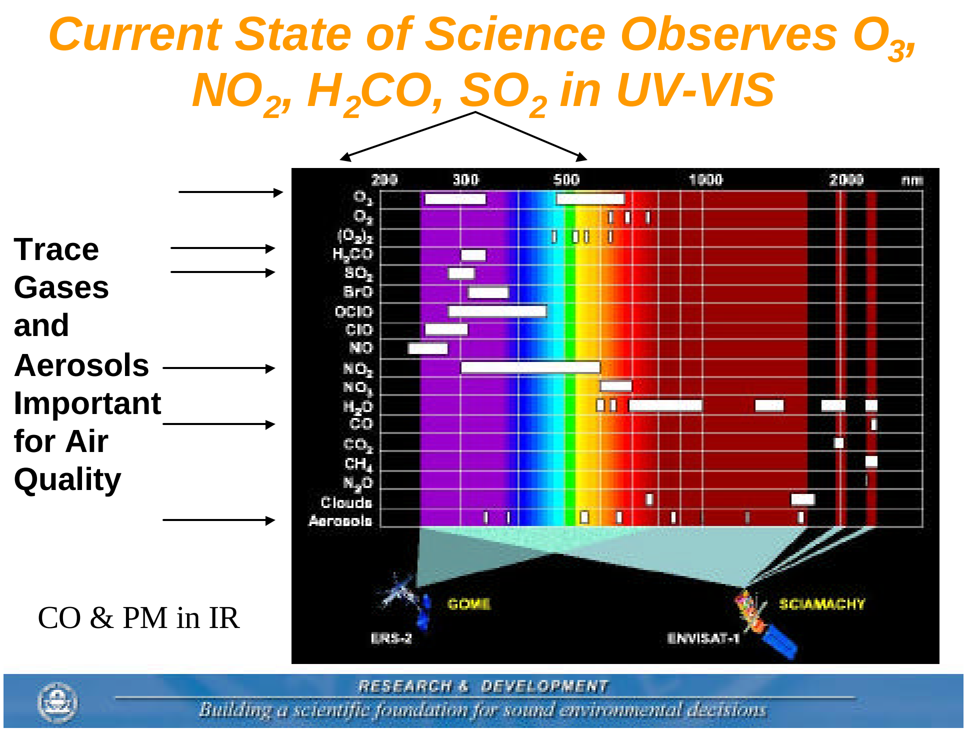


Figure 1. Air Quality Measurements

The EPA's AQI provides a daily indication of pollutant levels in local areas around the United States. EPA uses ground monitors to record pollution levels and produce the AQI for five air pollutants (PM, O_3, NO_2, CO, SO_2). NASA has numerous satellites collecting information on atmospheric conditions, including air pollutants (See Figure 2). For gaseous pollutants, there are several low-resolution measurements for global scale mapping (e.g., TOMS, GOME (Global Ozone Monitoring Experiment), MOPITT, Shuttle measurements, future EOS AURA and the European Envisat). For aerosols, the optical thickness may be retrieved by low-resolution sensors (TOMS) for global scale mapping, moderate-resolution sensors (e.g., AVHRR, MODIS, SeaWiFS) for continental to regional scale mapping, and high-resolution sensors (e.g., Landsat, EO-1) for regional to local scale mapping. NASA and EPA have compared their respective satellite and ground measurements and found strong correlations in their measurements.

Although satellite measurements are useful in understanding total atmospheric loadings of select parameters (e.g. aerosol optical depth), they do not provide sufficient detail to characterize ground-level concentrations. In order to predict and understand human exposures to both gaseous and aerosol air pollutants, ground-level or *in situ* observations are necessary, as are enhanced geostationary satellite observations (see Figure 3). Currently there are a number of ground-based air monitoring networks and databases maintained by EPA (AIRS, CASTNET, IMPROVE and others) that provide archives of long-term air monitoring. Several air pollutants are measured continuously in real-time (e.g. PM2.5/PM10, CO, O_3, NO_x, and SO_2).

Current Derived Tropospheric Observables for Air Quality

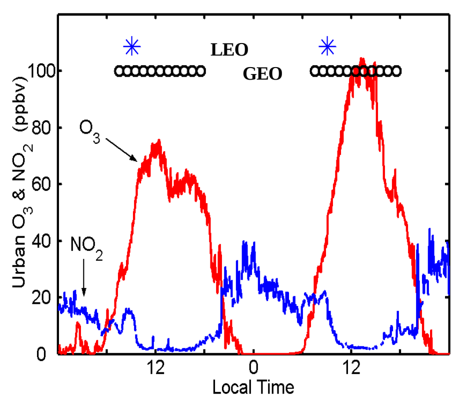
Pollutant	Current Sensors	Measurement
Particulate Matter (PM2.5) (as aerosol optical depth)	TOMS, AVHRR, MODIS, MISR, SeaWIFS, GOME, SCIAMACHY, GOES	Column
Ozone (O3)*	TOMS/SBUV, AIRS	Column
Nitrogen dioxide (NO2)*	GOME, SCIAMACHY	Column
Carbon monoxide (CO)	MOPITT, AIRS	Column
Sulfur dioxide (SO2)	GOME, SCIAMACHY	Column
Formaldehyde (H2CO)	GOME, SCIAMACHY	Column

*requires removal of stratospheric overburden

RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions

Figure 2. NASA Satellites Collecting Data on Air Quality

GEO provides the appropriate time resolution for air quality



O_3, aerosols, & precursors change rapidly during the day.

Stars indicate typical times for Low Earth Orbit (LEO) measurements
Circles indicate typical times for Geostationary Earth Orbit (GEO) hourly measurements
Red and blue lines indicate continuous ground-based measurements

Figure 3. Comparison of Ground Level and Satellite Measurements

Water quality/water pollution

Over one billion people in the world are without safe drinking water. Source water and downstream waters are compromised, and water treatment is uncommon. Water quantity is also a problem, affecting the source, and also limiting the capability to dilute polluted waters.

Water pollution has been studied extensively to assess environmental health. The primary water quality issues are associated with surface water, recreational waters and drinking water, each of which pose different challenges in understanding the impacts to public health and the environment. Surface waters include those used for transportation or economic interests as well as those used for drinking water. Issues associated with recreational waters include water-borne pathogens and contaminants that may have direct health effects or enter the aquatic food chain and finally are consumed by humans. Drinking water contaminants are primarily pathogens and chemicals that are consumed by humans, animals, and plants, and, thus, pose human health and environmental risks. Drinking water is further compromised by the absence of or limited nature of water treatment and subsequent discharge.

Ground-based observations and monitoring networks are vital part of these efforts and need maintenance and enhancement to continue to assess water quality. Remote sensing of surface waters has been possible for some time using a variety of satellite platforms including SEAWIFS, AVIRIS, MODIS and others. These observations have been useful in assessing, in particular, primary productivity (algal blooms, plankton growth, etc.), which may be impacted by environmental stressors.

Ground-based observations and monitoring networks are also an important component in assessing water quality and water pollution. EPA, USGS, NOAA and others have an extensive background in conducting monitoring networks and archiving data on surface waters and drinking water (e.g., BASINS, AQUA). Examples include the Watershed Assessment, Tracking and Environmental Results (WATERS), Safe Drinking Water Information System (SDWIS) and PRAWN – the Program Tracking database for Advisories, Water quality standards and Nutrients. PRAWN is an updated database containing information specific to surface and recreational waters. The USGS National Water Quality Programs (NAQWA) provide access to data from over 1.5 million sites around the country, including real-time and historic stream flow and stage data, ground water levels, water quality data, and site information at http://water.usgs.gov/owq/data.html. NOAA has a number of programs that track water in the atmosphere, on the Earth and in water systems.

In conjunction with *in situ* measurements, models, indicators and remote-sensing capabilities, existing databases serve as powerful tools useful in assessing environmental and public health.

UV Radiation

Ozone depletion and the associated increases of ground-level ultraviolet radiation are a serious health concern. Excessive ultraviolet radiation (UV) is well known to have a number of harmful effects on humans, such as sunburn and skin cancer, cataracts, and immune system suppression.

In addition to ground-based systems for measurement of UV radiation levels, a mature remote sensing system established in 1978 continues to provide daily measurements of UV radiation at the Earth's surface on a global basis from the Earth Probe/Total Ozone Mapping Spectrometer (TOMS). This system provides data and information in real time on the web and is used routinely for decision-making and early warning systems as well as for retrospective time series studies using the long-term data sets.

Ocean/Coastal Issues

Data on winds over the ocean, critical for hurricane and storm assessment, are monitored by Seawinds aboard Quickscat. Sea surface height and wave height are both derived from altimetry, most commonly from TOPEX/Poseidon, operated by NASA and France's Centre National d'Etudes Spatiales (CNES) and follow-on, JASON. Sea surface temperature, sea surface height and wave height have been useful in recent studies investigating the relationship between cholera outbreaks in Bangladesh and sea surface temperature, sediment load, phytoplankton abundances, and sea surface height.

Of the key ocean and coastal health-related issues recently defined, the most readily-addressed through remote sensing and *in situ* measures are harmful algal blooms (HABs), certain aspects of biotoxins, the dynamics of infectious diseases, pollutants, and extreme weather hazards. Evaluations of the ocean for health purposes is best performed with combinations of *in situ* (moored, buoys, shipboard, or surface-mounted) and remote sensor instruments to characterize the dynamics of this complex three-dimensional, patchy system. A number of remote systems have proven useful for observing the oceans for health purposes including sensors to measure ocean color, sea surface temperature, wave height, and sea surface height.

Observing ocean color is a means of determining ocean clarity and, therefore, enables detection of algal blooms, sediments, nutrients, and some contaminants important to studies and monitoring of harmful algal blooms (HABs), biotoxins, certain pathogens, and pollution. The systems most useful for these applications are SeaWiFS, launched in 1997 and the higher-resolution MODIS, launched in 1999. Sea surface temperature can be used for observing ocean circulation and ocean currents that transport algal blooms, pollutants and pathogens, and can be obtained from the NOAA, AVHRR, and MODIS thermal bands.

Although the coastal states have no common data system for data they collect, a few have monitoring programs designed to prevent human illness from shellfish poisoning syndromes and to monitor the environment for blooms and forecast their development and movement. In addition, state shellfish monitoring programs detect toxins in different fisheries species either to provide advance warning of outbreaks or to delineate areas that require harvest restrictions. Some states also have environmental monitoring programs for plankton and fish in coastal estuaries and bays to provide early warning of blooms. These programs monitor the abundance of a few harmful algae species either directly (i.e., counting cells), indirectly (i.e., satellite remote sensing), by measuring the levels of HAB toxins in both water and shellfish, and/or by determining environmental conditions conducive to HAB formation.

Local agencies perform routine analysis for bacterial contamination. They select among standard procedures and standard indicator bacteria and a monitoring schedule for collecting water samples and culturing for indicator bacteria. Results are obtained in 24-72 hours. In many instances, based on experience, indicator bacteria are simply assumed to be at high levels following rainfall events.

Contaminant Transport and Deposition

There are a number of system and programs for direct tracking of environmental contaminants by *in situ* and remote sensing technologies. These compliment the diverse suite of existing Earth remote sensing satellites routinely observing environmental parameters associated with the atmosphere, oceans, rivers, and sea ice which could be used for more aggressively monitoring the transport mechanisms that move contaminants from place to place.

Atmospheric transport, described earlier in this section under the air quality discussion, may best be observed through TOMS, MOPITT, MODIS, SeaWiFS, AVHRR, and Landsat. To observe movement of rivers, sediments, and, indirectly, associated contaminants, the following systems could be utilized: polar-orbiting microwave data from Radarsat and Synthetic Aperture Radar (SAR), and visible IR (infrared) data from SeaWiFS, AVHRR, and MODIS.

Movements of ocean waters, sediments, algal blooms and some pollutants may be observed through TOPEX/POSEIDON, SeaWiFS, MODIS, and/or AVHRR. Finally, sea ice extent, concentration, motion, and velocity are being monitored by global passive microwave (SMMR, SSM/I), synthetic aperture radar (Radarsat, ERS-1, ERS-2), and polar VIS/IR (MODIS, AVHRR, SeaWiFS). (Radarsat, ERS-1, ERS-2), and polar VIS/IR (MODIS, AVHRR, SeaWiFS).

Use of Genomics

Recent scientific advances have demonstrated that relatively long segments of DNA can be isolated directly from environmental samples. This capability will enhance our understanding of the genetic diversity and functions of microbial communities such as those related to ocean biogeochemical cycles and climate change. Determining the DNA sequence of the collective genome (also called "community" or "meta" genome) of the many organisms will allow inference of protein complexes and regulatory networks and, if done over time, on changes in the make up and overall health of a given ecosystem. This information will provide insights into the community's metabolic capabilities, including those of members that cannot be grown in laboratory cultures.

For example, ocean microbial communities play a critical role in regulating atmospheric carbon dioxide and the global climate by removing billions of tons of carbon from the air each year. Monitoring how populations change in different areas over time can provide a window into these vital processes and yield new strategies for mitigating global climate change.

In recent years, the genomes of numerous marine microorganisms, including the most abundant photosynthetic microorganisms in ocean surface waters (Synechococcus and Prochlorococcus), have been sequenced. The knowledge gained from further explorations into individual as well as metagenomes can be applied to develop high throughput ecogenomic sensors that will yield a new understanding of ocean processes, including those affected by climate change, pollution, or other local or global events. Such sensors can be incorporated into the advanced observation systems being proposed by Ocean.US (www.ocean.us) and the National Ocean Partnership Program (NOPP, www.nopp.org), a 15-agency consortium.

Thus far, the biological research planned for the Integrated Ocean Observing System (IOOS) is limited to conventional measurements of species and abundance of fish and zooplankton, species of phytoplankton, and optical observations. This new capability would greatly enrich IOOS data with genomic observations and advance the shared goal of improving predictions of climate change and its effects on coastal populations.

A number of scientists have pioneered the application of genome science to ocean research in fairly small scale, short-term studies performed from ship platforms. The high-throughput approaches envisioned for ecogenomic sensors would merge the knowledge gained from genome research programs with nanotechnologies and smart sensors to refine the measurements of important biological nutrients and other physical and chemical parameters of nanoscale environments—the same scale at which microbes live. These can be placed on IOOS platforms and on autonomous underwater vehicles, such as depth-profiling carbon explorers, to survey the metagenomes of deeper U.S. coastal waters and major ocean basins. The data collected will lead to a comprehensive and predictive understanding of ocean cycles and the effects of global climate change, pollution, and other environmental perturbations on the world's oceans.

Living organisms integrate environmental information and reflect the physical-chemical characteristics of the surrounding environment. Ecogenomic sensors could help to answer key questions such as the following:

How is climate change affecting key microbial communities involved in carbon fixation and sequestration?
Is the balance changing between autotrophic (carbon dioxide fixing) and heterotrophic (carbon dioxide producing) microbial communities?
Have changes occurred in sentinel species that can warn of impending ecosystem changes? For example, are red tide or Pfiesteria species increasing in abundance? Such increases would have broad economic impacts.

Ultimately, applying the exciting science of genome research programs to planned ocean observation systems such as IOOS will provide a tangible, high-impact product that address global scientific and societal needs.

4. Major Gaps and Challenges

In order to create a comprehensive, useful Earth observation system, it is necessary to enable the easy transfer of environmental information to researchers, response communities, and policymakers. Thus, it is important to develop user-friendly systems for quick access to Earth science data. However, many factors have hindered the use of space- and ground-based data for health applications. Some of the most important are:

1. Lack of appropriate spatial, temporal and spectral resolution measurements by the current ground or *in situ* and satellite sensors.

2. Lack of good communication and understanding between the data producer community and users in the health and environment fields of research.

3. Complexities associated with health and environment relationships due to the diversity and number of variables.

4. Absence of continuous temporal and spatial data sets required for the study of specific diseases or disorders, including human activity patterns.

5. Difficult access to data and value-added products due to differences in format, resolution, projection, computer systems and lack of an integrated system with generally accepted standards for unified studies.

6. Limited access and high cost of high-resolution *in situ* satellite remote sensing data.

7. Insufficient technology transfer methods to move from research to operational environments, and need for an information system.

8. Inadequate development of remote sensing and ground-based methods to continuously monitor environmental pollutants (including speciation) or their indicators affecting human health.

9. Lack of ongoing observation systems available for collecting human activity or human exposure data. Data are currently only available on a study-by-study basis.

A focused effort is needed to improve technology transfer and development of user-friendly tools, indicators, models and decision support systems for the mass distribution of data and products. In addition, effective implementation of these systems requires the promotion of both public and private sector use and dissemination of observation data/products and effective technology transfer in order to extend the combined use of ground or surface measures, remote sensing, and models and decision support systems beyond the traditional science community to be applied to the needs of decision-makers and the public. This, in turn, requires the development of information systems to communicate more efficiently observations, information, indicators, models and decision support systems. In particular, the combination of *in situ* measurements and remote sensing data along with geographic information systems (GIS), global positioning systems (GPS), models, indicators and others are fundamental tools for the planning, analysis, surveillance and intervention in the control and management of infectious diseases outbreaks. To take full advantage of these technologies, they need to be fully integrated with one another in order to benefit the end-user in a timely and cost-effective way.

A much better understanding of the transmission of infectious disease would be obtained by increased use of high-resolution hyperspectral sensors. The ability to call up quickly overflights during cholera epidemics, for example, would be invaluable. Multitemporal images at 3-4 resolution of regions with seasonal epidemics of diseases influenced by environmental factors would be helpful for establishing local conditions in oceans, estuaries, coasts, and rivers as diseases emerge, if a data-purchase arrangement can be made appropriate to research applications and the budgets of the relevant countries.

Many infectious diseases are greatly impacted by the weather and by patterns of agriculture. Qualitative and quantitative analysis of agriculture and vegetation cover remains a key need. Improved resolution will assist to identify, understand, and predict crop yields and evaluate the scale of potential problems in the food supply and its transportation, such as crop failure and famine or unexpectedly high yields that may presage a booming rodent population and associated disease risks. Salinity and turbidity are important features, but while many studies have shown that salinity is correlated with spectral reflectance, this is quite difficult to control for, and improved products would be helpful.

An immediate need is to greatly improve the spatial resolution of Earth observation for specific epidemic areas that are also well-served by on-the-ground disease, demographic, ecological, or other information (e.g., at field sites). This will form the basis for developing new correlates and will inform the evaluation of historical remote sensing data with historical data on epidemics and the establishment of disease prevalence patterns. The number of diseases that can be productively studied with poor spatial resolution is very limited.

The interactions of pathogen populations with human populations represent a critical area of human health research. In cases where transmission between humans involves water, an aerosol, or a vector-mediated stage, the space between humans becomes critical in determining if disease transmission is positive or negative. The better the spectral, spatial, and temporal resolution, the more likely it is that true associations will be identified, and the more applicable remote sensing will become to infectious disease prediction and control. It is essential that a concerted effort be directed to developing user-directed data products that are supported by on-the-ground physical, biological, epidemiological, and census studies. Additionally, it may be appropriate for user-directed specifications to be included in new space- or airplane-based instrumentation that will be available to participants to obtain data contemporaneously with unexpected disease emergence.

It is important to note that most research linking environmental exposure to the increased prevalence or exacerbation of asthma and allergy is based on *in situ* measurements in the local environment. Significant bodies of information exist within discreet scientific domains. For example, geologists have studied quartz particulates in dust clouds; aerosol physicists have studied aerosolized pollen behavior, but the behavior of mixed materials within a single cloud and the biological consequence of mixed exposure are not clearly understood. Currently, access to satellite data is limited, there is minimal support for data sharing, and very few multidisciplinary teams exist that are equipped to evaluate the relationship of these physical phenomena to disease outcomes and public health practice.

Application of enhanced *in situ* and remote sensing data and techniques to air quality evaluations is very promising, and a potential area for early, demonstrable results. Efforts like the State of New York GRID air quality forecasting system, a joint effort between the State, EPA and NOAA, should be encouraged to demonstrate the promise of forecasting conditions for the public and decision-maker, but also track the results to see if forecasting produces improved air quality by people and governments making decisions that reduce pollution.

Additional challenges include the following needs:

- A framework within the scientific community regarding data sharing – health, plant, animal, and environmental
- Agreed-upon standards for comparison of disparate sources of data and for establishment of interoperable systems
- Conversion of paper documents that contain useful date to a standardized digital format
- Provision of temporal and spatial data with enough parameters to be useful in both static and dynamic models
- Validation of historical, baseline and real-time data
- Improved metadata
- Uninterrupted time series environmental data – historical and future
- Integration or linkage of data collected in a laboratory with that for the same environmental agent collected in the natural environment
- Collection of data at appropriate spatial scales to inform relevant regulatory action/emergency response
- Improved Data archiving to allow for a better understanding of the development of chronic diseases and diseases resulting from long-term environmental exposures
- More extensive databases on human activities to integrate with pollutant concentrations to estimate exposures
- Integration and display of data from multiple scientific disciplines in a meaningful way in order to create a successful integrated observation system that is useable by members of the environment; human, animal, and plant health communities, and by decision makers
- Improved surveys of food contaminants and consumption patterns
- Better indicators for bacterial/chemical contamination of water resources
- Routine monitoring of sea surface temperature to aid in predictions of bacterial contamination in recreational and shell fishing areas.
- Appropriate spatial and temporal resolution data to relate directly to exposure or human health. Models should be developed to predict or forecast exposures.
- Archive model outputs for use in future health and epidemiological studies to determine relationships between environmental exposures and disease
- Continued research on use of genomics in monitoring for environmental factors that influence human health and well-being

5. Future Earth Observation Systems that May Fill Gaps

The current *in situ* and remote sensing technologies offer great potential for human health studies. It is important to maintain and enhance existing systems. Clearly, the advent of geostationary sensor systems with improved spatial and spectral resolution could allow study of air, weather, wetland, water and related phenomena that have influence. A day/night sensing capability is important in the UV, visible, near, middle and far infrared as well as the microwave regions. A denser network of air and water quality observations would be very helpful.

A number of efforts could be enhanced by the use of synthetic aperture radar (SAR), including the disasters and hazards societal benefit. This technology is especially useful because it is capable of operating day or night and can obtain data through clouds. While a number of technical difficulties such as data interpretation, calibration issues, software, and problems related to topography have prevented this technology from widespread use in public health studies to date, the potential for its application to public health issues is great because it would enable collection of information on important parameters such as accurate land cover change characterization, delineation of water bodies and flooding extent, and soil moisture.

The future NPOESS system will have much of the capability of the MODIS instrument. It will provide vegetation, land use/cover variability (as a replacement for Landsat), surface temperature and some soil moisture capability, along with cloud and aerosol detection. However, the spatial resolution will not be much different from current instruments. The need for very high spatial resolution sensors to monitor mosquito-breeding sites will continue. For precipitation measurements, the Global Precipitation Mission has great promise, but it is going to be delayed to about the end of the decade for launch.

For coastal managers, new remote sensing technologies such as optical detectors, autonomous underwater vehicles and satellite sensors other than SeaWiFS are being developed to detect and track HAB movements in time to take proactive measures to protect public health. The NCCOS Center for Sponsored Coastal Ocean Research (CSCOR), through the ECOHAB and MERHAB programs, supports research on rapid and highly selective tools and sensors for monitoring and testing of harmful algal blooms. These prototype tools are aiding in the assessments of public health impacts of harmful algal blooms, the detection of toxins and harmful species at low concentrations, and to understand the effects of sub-lethal exposure to toxins. New remote sensing technologies such as optical detectors, autonomous underwater vehicles and satellite sensors are also being developed to detect and track HAB movements in time for coastal managers to take proactive measures to protect public health. Some of this technology has already been incorporated into ongoing testing programs and has allowed for the proactive opening and closing of shellfish harvests. Efforts are underway to incorporate successful sensors into regional observing systems.

In addition, CSCOR supports development of a suite of coupled physical-biological ecosystem models to enable timely ecological forecasts for a variety of key management concerns such as harmful algal blooms, hypoxia, fisheries, and cumulative coastal impacts. These models will ultimately be transferred to state and federal management entities and incorporated into regional observing systems.

Recent scientific advances have demonstrated that relatively long segments of DNA can be isolated directly from environmental samples. This capability will enhance our understanding of the genetic diversity and functions of microbial communities in soil and water and offers the opportunity to develop new sensors for the presence of organisms that impact on human health or for ecosystem changes that enhance the likelihood of their proliferation (e.g., red tide or pfiesteria).

6. Interagency and International Partnerships

Due to the multiple factors involved in addressing environmental health issues, scientists from many disparate disciplines who are not accustomed to working together are needed to address these issues. Therefore, to create a successful integrated observation system usable by members of both the environment and health research, management, and policy communities, partnerships among these disciplines and stakeholders are essential. Strong partnerships help ensure that the appropriate data sets are collected, integrated, interpreted, and used properly. While there are a number of interagency partnerships, which exist at this time, most were developed on a project basis and are frequently between researchers within individual agencies and institutions. These partnerships are generally specific to the project under development and are contingent on continued researcher interest and funding. It will be critical to make an aggressive effort to develop a system of comprehensive partnerships among agencies, states, and other parties in order to create a useable as well as useful observation system. In addition, Consistent practices, interoperability, and information sharing among State and local agencies that gather data are needed.

Examples of existing partnerships include: NOAA/NWS provides weather forecasts to CDC staff who are involved in research on the effects of heat waves and in working with State and Local officials to prevent heat-related morbidity and mortality. Similarly, HHS and FEMA for their disaster preparedness and response roles rely on NOAA/NWS to predict the location and severity of extreme weather events. EPA and NOAA have partnered to produce multiday forecasts of air pollution and air quality in cities throughout the U.S. NIEHS researchers use EPA data on air and water quality for health effects studies. UCAR/NCAR provides UV exposure data for melanoma studies. University researchers in the U.S. and abroad supported by the NOAA/EPA/NSF/EPRI Program on Climate Variability and Human Health use observational data from NOAA, NASA, CDC, and state and local public health agencies to characterize the link between vector-borne diseases and climate with the goal of developing early warning systems for disease outbreaks. NIAID and NASA have an interagency agreement to support training for African scientists in the use of new technologies for the control of malaria. The purpose of the initial effort was to determine if remotely sensed information could be used to develop predictive models for risk of malaria transmission.

Bacterial contamination is monitored by local public health agencies, and these same agencies use the data. NOAA, EPA and other Federal agencies assist by providing updated methodologies. National databases on bacterial contamination are updated by collecting data from state agencies that, in turn, collect it from the local agencies that made the measurements. The USGS National Biological Information Infrastructure (NBII), which is composed of multisector partnerships (Federal, state, and local agencies; universities; private industries, and nongovernmental organizations), provides increased access to biological data and information on our nation's plants, animal, and ecosystems to a variety of audiences including researchers, natural resource managers, decision makers, and the general public.

Environmental monitoring that crosses national borders is often best coordinated by the appropriate international organizations. For example, the international aspects of bacterial water quality monitoring are best handled through the World Health Organization or, in the Americas, through the Pan American Health Organization. New partners from the remote sensing and environmental community could provide useful contributions to those monitoring activities.

7. U.S. Capacity Building Needs

Relatively few individuals presently are able to bridge the gap between the Earth observation data and the health communities that use that data and data products. Clearly the full value of Earth observation data being used with health data will not be realized until we have more individuals trained in this specialty. For example, training for both the malaria teams and those charged with developing predictive models for climate and other factors that regulate mosquito vector populations, and therefore, the transmission of the parasite is imperative.

Education and training for people who design, build, and operate observing systems, who analyze data, and who produce data products are ongoing needs. Conversely, building institutional willingness and capacity in public health to move beyond surveillance and response to prediction and prevention by effectively using observational data in new decision support tools will be essential. The federal sector should continue to work with state, local and private sector service providers and authorities to enhance planning and response capabilities.

The need for education and training at all levels in developing countries is as great as the need for equipment to gather and process data. Examples where the U.S. is working to increase capacity in developing countries include the Fogarty International Center at NIH/HHS International Research Training in Environmental and Occupational Health Program, which provides short-term, long-term, degree-oriented and post-doctoral training to developing country scientists in their home countries and in the U.S. It also provides grants for collaborative research between U.S. and developing country scientists through its Health, Environment and Economic Development Program now operating in 11 countries. NASA, NOAA, EPA (STAR grants and fellowships), and other Federal agencies also have programs for capacity building in related areas. It is important to continue and expand these special efforts to build appropriate capacity in developing nations where health and well-being problems are often overwhelming. This is a complicated issue--in developing countries, for example, it is not necessarily a lack of knowledge that often prevents enforcement of standards; rather, limited public health funds that are devoted to more pressing problems.

8. Conclusions

Healthy Public – Societal Imperatives

A growing world population, projected to roughly double in the next few decades, will increasingly demand access to crucial resources like clean water and plentiful food. The concentration of populations is shifting from rural areas to urban centers, many in low-lying coastal regions or seismically active zones. In the United States, more than half of the population lives within 50 miles of our coasts, areas particularly vulnerable to storm surges and flooding, and water and air quality issues. We rely upon coastal regions for healthy fisheries, and reliable transport and navigation. Increased dependence on infrastructure networks (roads, power grids, oil and gas pipelines) increases our potential vulnerability to natural disasters, and requires improved understanding of the complex workings of Earth systems in order to protect society and manage our resources in a more efficient and effective way.

The ability to predict the appearance and intensity of diseases has long been a goal of public health workers, economic planners and ordinary citizens. For those diseases that are influenced by environmental factors, the development of predictive indicators and models will open the door to the possibility that if one could link risk of disease with certain variables, one could eventually apply these indicators and models to predict occurrence and possibly control or prevent these diseases in human populations.

All the components of the integrated Earth observation system contribute to improving human health and well-being. Researchers, service providers, policy makers, and the public use Earth observations to make decisions and take actions. These decisions and actions help reduce the impact of disasters, protect and manage natural resources, adapt to and mitigate climate variation, support sustainable agriculture, forecast weather, protect areas valued for recreational, religious, or aesthetic purposes, and prevent disease/dysfunction due to environmental exposures or conditions that increase the likelihood of transmission of water- or vector-borne diseases.

Considerations for Future Systems

- Higher spatial and temporal resolution. The combination of improved and enhanced ground or surface measures and high spatial resolution and repeat coverage over an area are among the most critical parameters for future instruments, regardless of the channels utilized.

- Flexible information system. The system must allow for continuous updating with new and additional information in a near-real time scenario for flexibility in the types of information and the method of update.

- Improved access and use of remote sensing data. Easier access to improved and enhanced ground or surface measures and use of remote sensing data is needed, as well as capacity building, communications and outreach to foster the use of data, information, models and decision support systems

- More continuous temporal and spatial data sets for disease studies. Developing methodologies to measure environmental stressors in real-time across large spatial domains will enable better prediction and forecasts of exposures and possibly the development of diseases caused by exposures.

- Expansion and development of interdisciplinary (health-environment) research and activities.

- Formation of a distributed federation of data bases (including ground based and health data). The collection of quality data to predict changing environmental conditions is needed. Provisions for sharing environmental and human, plant, and animal data on a timely basis in a distributed federation of databases designed to make existing information more accessible need to be put in place in the form of an information system. Standards to compare disparate sources of data are needed, and adequate metadata should be developed for all data collected. The use of bioinformatics and state-of-the-art information technology capabilities (e.g., geospatial, visualization) to increase understanding of the effects of environmental factors on human health and well-being should be encouraged. Models that can handle multidisciplinary data, including a national capability in infectious disease modeling, should be further developed.

- Interoperability. Coordinated data management and interoperability across agencies and user groups is required a system of Earth observation systems.

- Development and implementation of a surveillance program to monitor the presence in the environment of disease organisms, their vectors and natural reservoirs.

- A surveillance and monitoring program for air, water and land pollution episodes. Improved assessment of pollution episodes caused by natural and anthropogenic processes will lead to better protection of public health and the environment.

- A surveillance and monitoring program for assessing human activities and locations. Without better knowledge of human activity patterns and the locations of people it will be very difficult to forecast or estimate exposures to pathogens, vectors, or environmental stressors.

- Development of improved sensors for HABs and their toxins

- Increased interdisciplinary research to develop and integrate modeling, retrospective, broad-scale, and process studies that underpin the decision support tools needed to solve real-world problems.

- Develop improved and faster indicators for the human disease potential of recreational and shell fishing waters.

- Continued support for national biological information systems, such as the USGS National Biological Information Infrastructure (NBII) and the NBII Wildlife Disease Information Node. Data and information maintained by federal, state, and local agencies, universities, and the private sector are linked through the NBII gateway and made accessible to decision makers, researchers, natural resource managers, educators, and the general public.

- Develop satellite-based sensors to measure vertical profile of atmospheric contaminants (PM, air toxics), especially at ground level. This is especially important to better characterize inhalation exposures of toxic airborne compounds.

- Develop remote sensing capabilities to monitor emissions inventories from natural and anthropogenic sources in real-time. Current emission inventories are either self-reported or based on a few measurements scaled on an annual basis. Improved databases of emissions inventories will enable better prediction of source impacts on the environment and public health.

- Build an across-the-board system for training and education at the intersection of environment and health observations, data collection and analyses.

- Increase research on use of genomics in monitoring for environmental factors that influence human health and well-being.